Kinoform Diffractive Optics by Electron Beam Lithography

Project Number: 97-02

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Purpose

This effort focuses on the development of new diffractive optics fabrication processes, using a direct write electron beam lithography system at Marshall. To produce high-quality diffractive optical components, one needs the capability to shape, or "micromachine," the desired optical surface profile with submicron precision. The primary advantage of the direct write approach is that a single processing step is required to create the continuous-profile (kinoform) diffractive element. Writing directly on the substrate is highly superior to the standard "binary" masking approach using optical lithography (in which several photoresist exposure, development and substrate etching cycles are required) due to a tremendous reduction in spatial fabrication errors and a reduction in time required to fabricate the optic. The purpose of this research is to clearly determine the advantages and limitations of the direct write, electron beam lithography approach for fabrication of diffractive optical elements.

Background

Direct write fabrication approaches are now emerging as viable manufacturing tools for producing diffractive optical elements with stringent design requirements; these primarily include focused laser writing in photoresist and electron beam lithography in electron beam-sensitive resists and glasses. High-performance diffractive optics offer optical system designers with new degrees of freedom that can be used to drive future photonics-in-space technologies needing advanced sensors, high-speed data transmission, real-time information processing, high-density data storage, and high-resolution displays. The research reported here is being conducted as a team effort between MSFC and the U.S. Army Air and Missile Command, Weapons Sciences Directorate Research, Development, and Engineering Center. The effort is funded through partially reimbursable funds that stem from a DARPA-sponsored Technology Reinvestment Project activity in which MSFC and AMCOM are participants. The elements created under this activity will also serve as master elements in a replication process being developed by an industrial partner, as defined in an existing MSFC Space Act Agreement.

Approach

The approach for FY97 has included the writing of test patterns in PMMA (polymethylmethacrylate) in order to determine the operational characteristics of the electron beam system and the interdependence of exposure dose, development and the resulting depth of surface relief in the PMMA. Also, a number of diffractive lenslet arrays and computer-generated holograms were designed per specification of commercial test-bed applications. Also, an approach was taken to enable the pattern generation software of the electron beam system to use the variable dwell capability inherent in the hardware design of the electron beam system.

Accomplishments

Test patterns consisting of a series of binary gratings with 1- to 32-micron feature sizes were developed. Figure 41 shows one such grating. Each set of these gratings was written at seven different dose levels by writing or overwriting each pattern up to seven times. Each write was done using the same dwell time and current density.

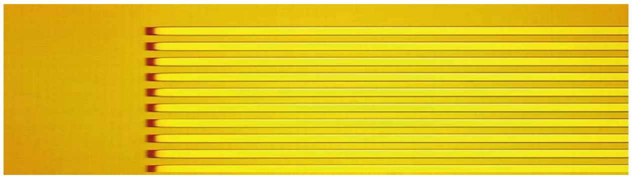

FIGURE 41.—Test pattern.

An initial relationship between dosage and resulting depth was determined in this manner; however, each time the electron beam column is realigned or recalibrated this relationship must be reestablished. Based on the functionality determined, a microlens array shown in figure 42 was generated. The lens shown is 225 microns in diameter with a speed of f/3. Each of the 16 annular zones is made of 4 vertical step heights. This design was implemented using four separate exposure files, each set at a different exposure dosage level. This multiwrite process was necessary due to original limitations on the direct dose control in the original pattern generation software.

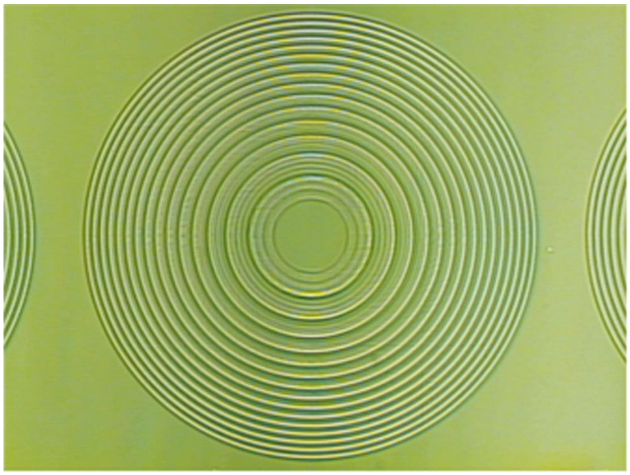

FIGURE 42.—F/3, 225 micron, lenslet array.

Significant modifications to the pattern generation software in FY97 now make use of the variable dwell capacity inherent in the hardware design of the electron beam system. This software upgrade allows direct control of the dose, and consequently the depth, of each fundamental pattern element (box, polygon, or arc)—a newly enabled and highly desirable feature for diffractive optics fabrication. A 16-level blazed grating was fabricated using the direct dwell time extension to control exposure dose. This element was delivered to an industrial partner for testing and replication.

Future Work

The electron beam exposure and development process will be optimized for PMMA and applied to specific final test-bed design requirements. Test structures to verify the smallest feature size producible are planned. A newstart RTOP in FY98 is underway which will use the electron beam system for variable dose exposure by electron beam of a new gray scale masking material. This will be studied as an alternate approach to creating diffractives in PMMA.

Funding Summary ($k)

	FY97	FY98
Requirements:	0	0

Manpower

	FY97	FY98
Requirements:	3 man-years	3 man-years

Status of Investigation

An extension from September 1998 to November 1998 may be required for completion. The electron beam lithography system has experienced hardware damage due to many power fluctuations and outages during FY97. An uninterruptible power supply has been procured, and was originally scheduled for installation in October of 1997; however, the vendor indicated delivery will be in April 1998. Unfortunately, the time and talent required to repair damage, coupled with system downtime, has reduced the level of research originally planned for FY97.